Coupling phenomenological model of expansion with mechanical model of starchy products extrusion (Projet AIC 'QualExp' 2013-2015)

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Magdalena KRISTIAWAN (BIA-MC2)

Problème d'application INCOM : **Couplage/Réduction de modèles**

Partners

- INRA: M. Kristiawan, K. Kansou, G. Della Valle (BIA); A. Ndiaye (I2M)
- CEMEF: B. Vergnes
- SCC: C. David

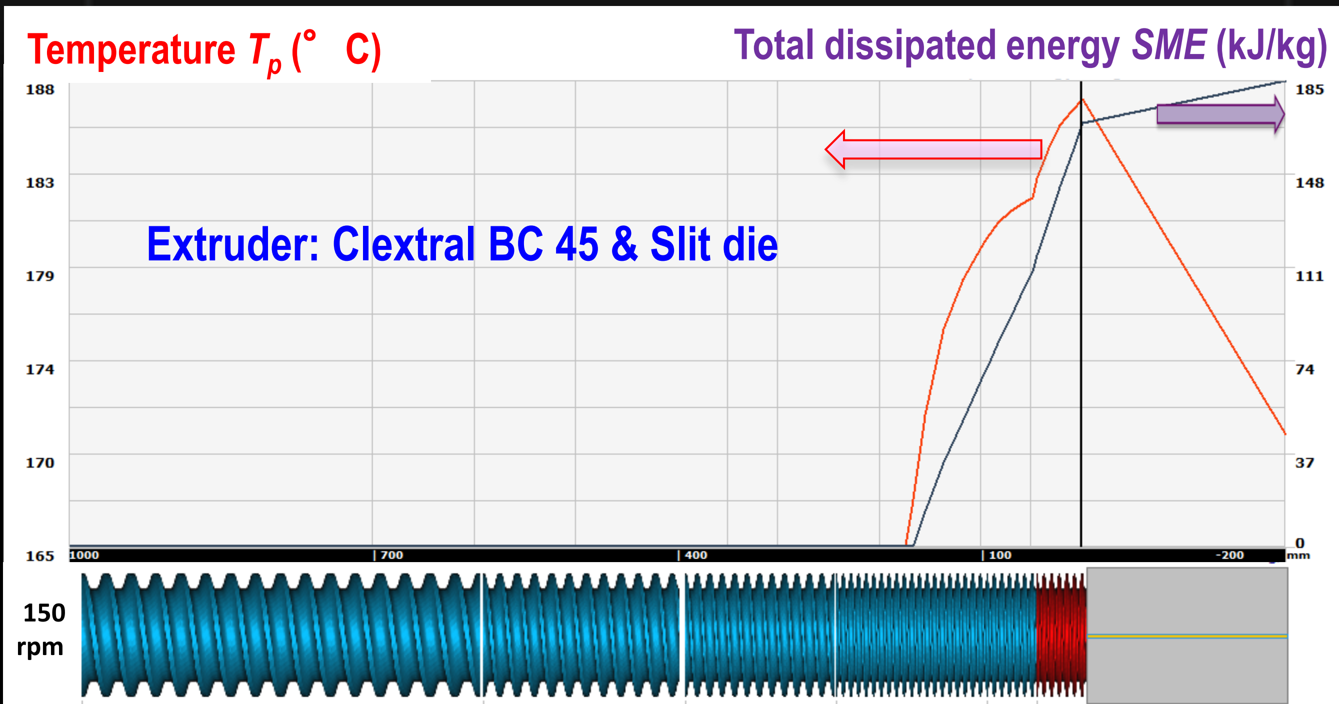
Examples of application

- Innovative starchy foods, with modulated shape and digestibility
- Starch based shape memory biopolymers for medical devices

Coupling between expansion and 1D mechanical Ludovic® models

(Logiciel d'Utilisation de DOubleVIs Corotatives)

Starch
+*MC*
(% water)



Hopper

Die

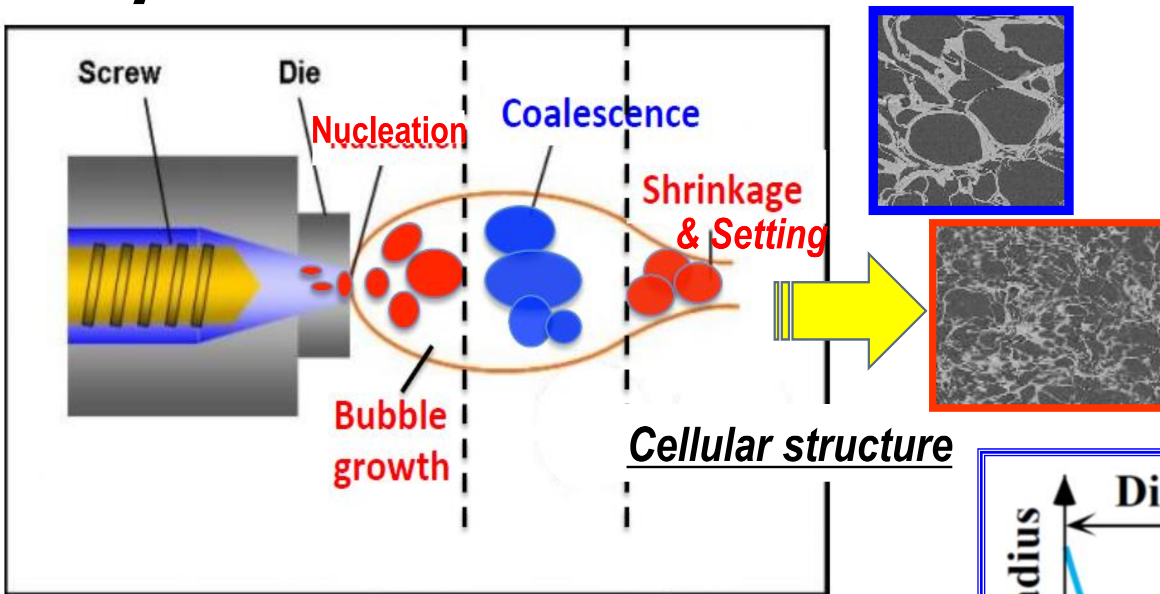
T_p, *SME*, *Viscosity* η_s
+ *MC*

« Ludovic®'s output variables at die exit = input of expansion model »

« New Ludovic outputs = macro & cellular structure of foams »

Context : **Expansion** by extrusion

Acquisition of texture



Deterministic models:

- *Unsatisfactory*
- *Complex ↔ Ludovic®*

State diagram

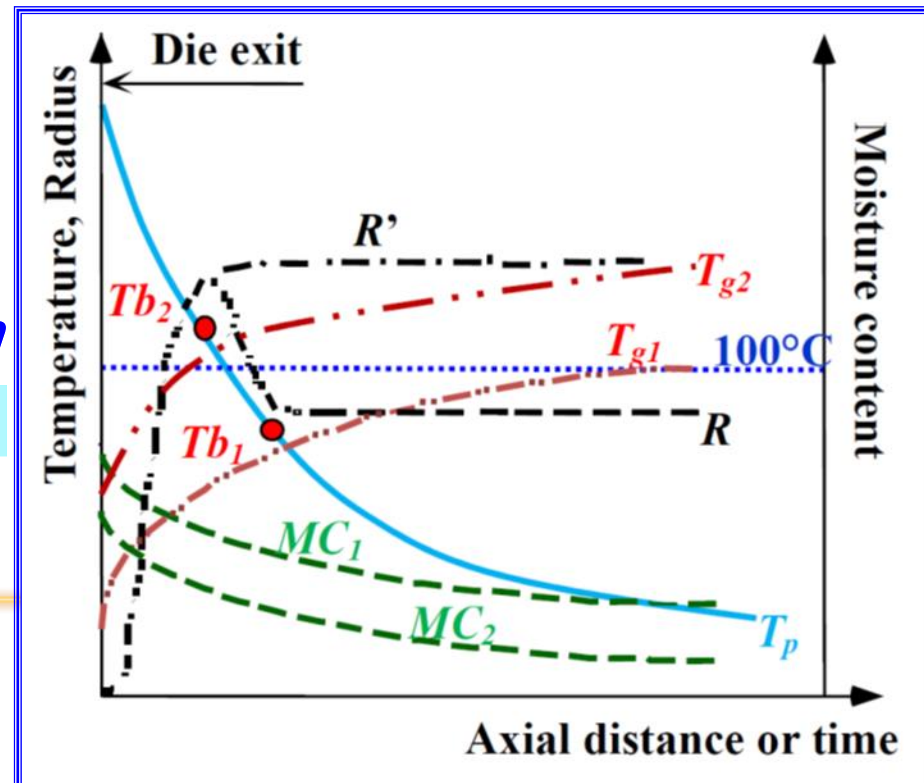
The bubble growth stops at Tp ≥ Tg + 30° C

MC = product water content

T_g = glass transition temperature

T_p = product temperature

R = bubble radius



Methods and Resources

Phenomenological modeling of **bubble growth** in a **viscoelastic** biopolymer matrix in the transition state from rubbery to solid phase.

Macro & micro structure = f (Water%, T_p °C, *SME* kWh/t, **shear** & **elongational viscosities**)

Approach

Achieved

1) Validation of Ludovic® extrusion simulation for starchy products

- Ludovic®'s **output variables** at die exit = input of expansion model

2) Collection & Representation of knowledge (scientific)

- *Concept map*

3) Establishment of phenomenological models of expansion

- Model validation on more complex starchy products

Ongoing

4) Relation between anisotropy and cellular structure (fineness)

← **5) Coupling between expansion & Ludovic® models: INRA & SCC**

Output variables

- **Macrostructure (360 data, maize starches)**

  Volumetric Expansion Index (*VEI*)

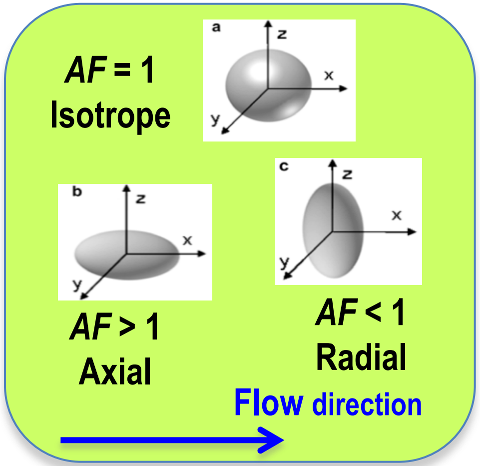
  $$VEI \approx \frac{melt \quad density}{foam \quad density}$$

  - **Radial Expansion Index (*SEI*)**

  $$SEI = \frac{foam \quad cross \quad section}{die \quad cross \quad section}$$

  Anisotropy Factor (*AF*)

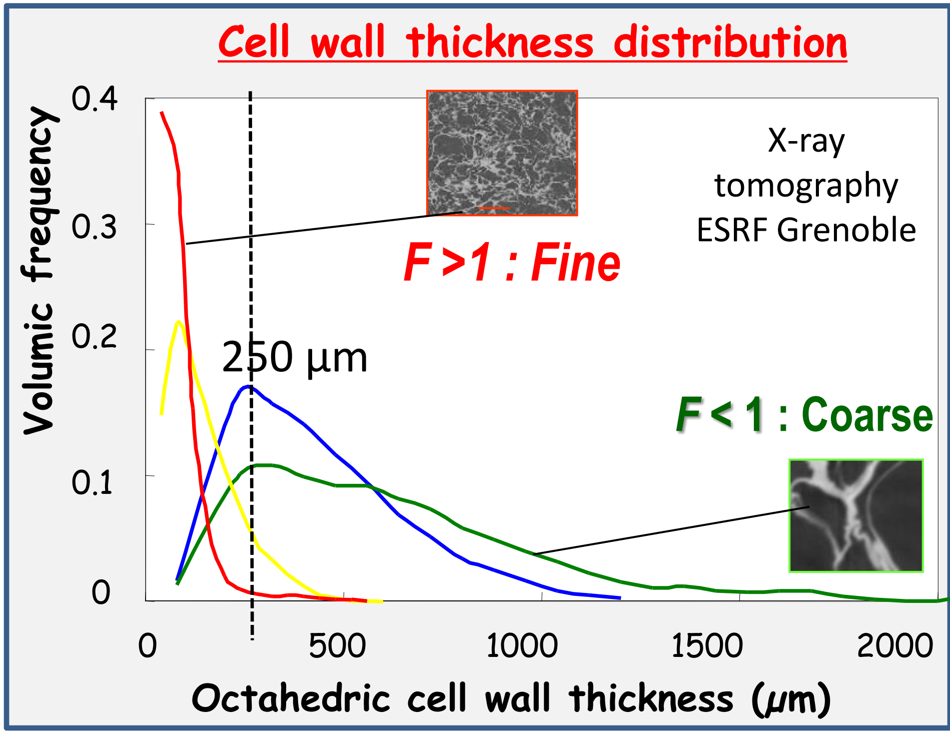
  $$AF = \frac{VEI}{SEI^{3/2}}$$



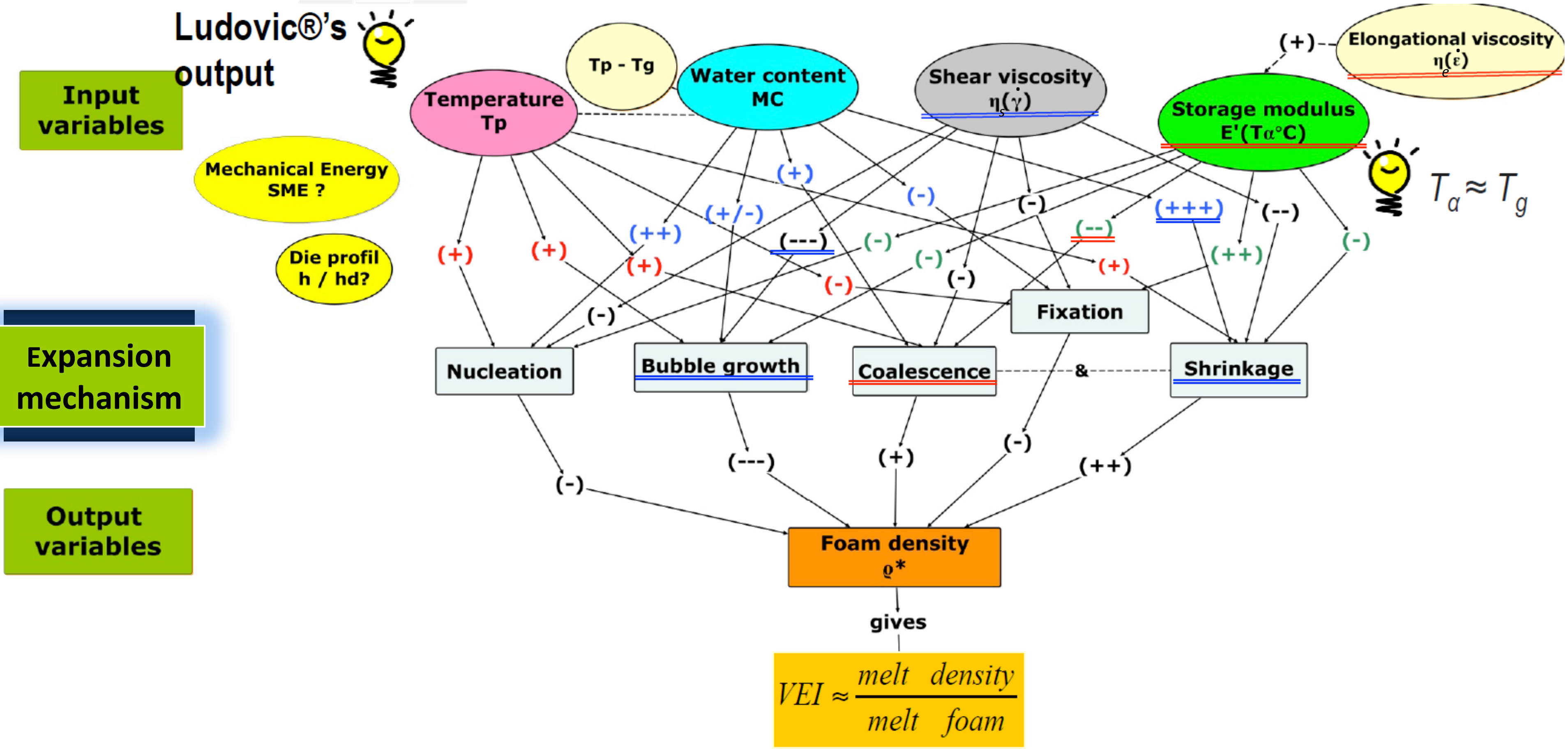
- **Microstructure: Cellular Fineness (*F*)**

$$F = \sqrt{\frac{\left(\frac{250}{MWT}\right)^2 + \left(\frac{1}{MCS}\right)^2}{2}}$$

MCS = Mean cell size (mm)
MWT = Mean wall thickness (µm)



Concept map: Phenomenological model of expansion



$$VEI \approx [MC]^x \otimes [Tp]^y \otimes [\eta(\dot{\gamma})]^z \otimes [E'(T_g)]^t$$

General expansion model: $SEI = \alpha.(\eta/\eta_0)^n$

E' = storage modulus

$$a = b_0 (MC/MC_0)^{b_1} (Tp/Tp_0)^{b_2} (SME/SME_0)^{b_3} (E'/E'_0)^{b_4} (h/h_d)^{b_5}$$

$$n = b_6 + (MC/MC_0) b_7 + (Tp/Tp_0) b_8 + (SME/SME_0) b_9 + (E'/E'_0) b_{10} + (h/h_d) b_{11}$$

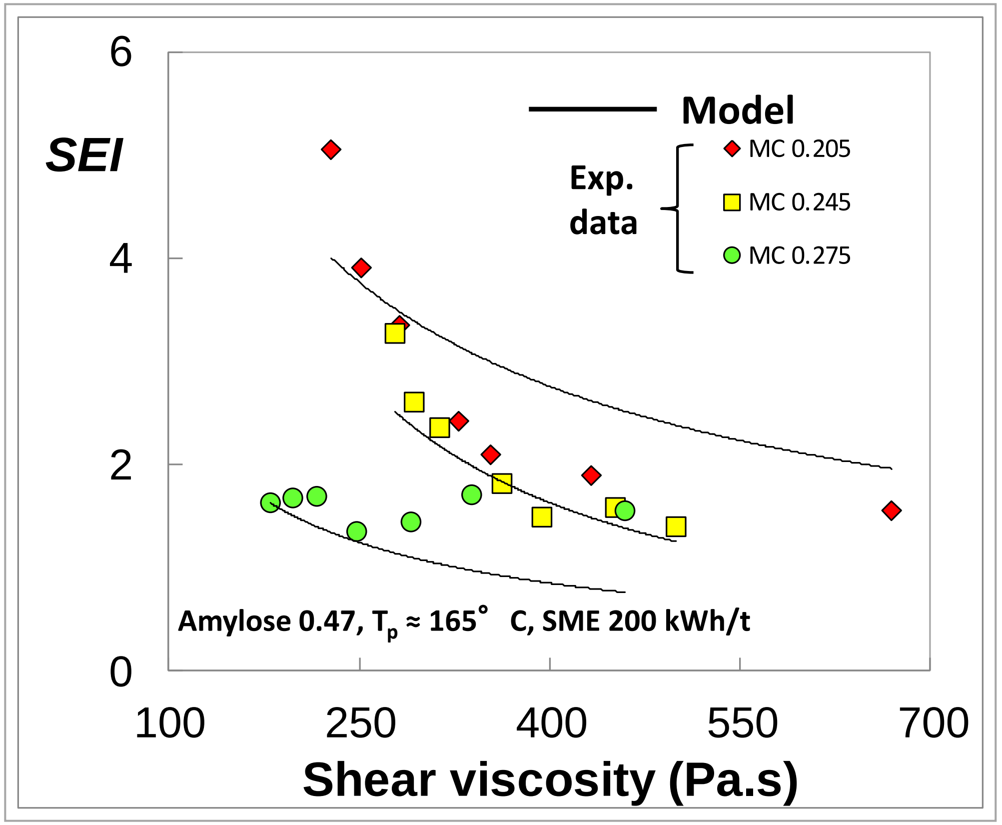
R^2 adj = R^2 = 0.78; *ddl* = 348

Significativity of model parameters

a	b_0	constant	
	b_1	***MC* water**	**---**
	b_2	T_p ° C	-
	b_3	*SME*	-
	b_4	$E'(T_g)$	++
	b_5	h/h_d	+
n	b_6	constant	
	b_7	*MC* water	-
	b_8	T_p ° C	-
	b_9	*SME*	n.s.
	b_{10}	$E'(T_g)$	n.s.
	b_{11}	h/h_d	n.s.

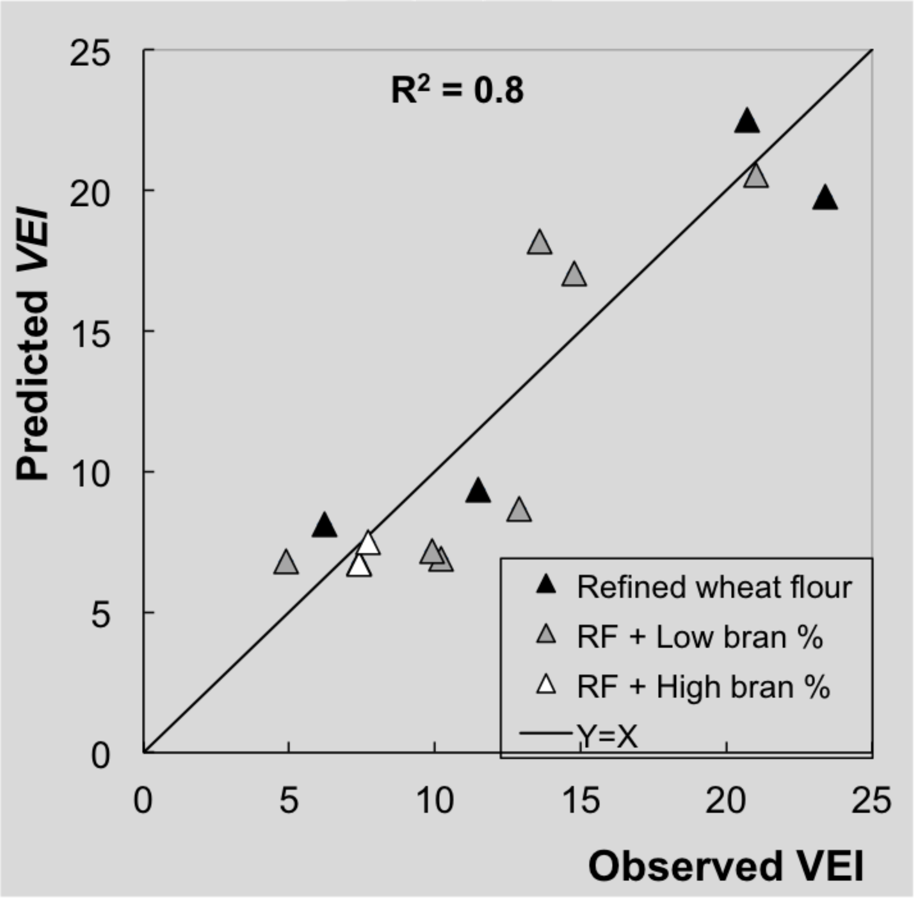
--- or +++ = most significant

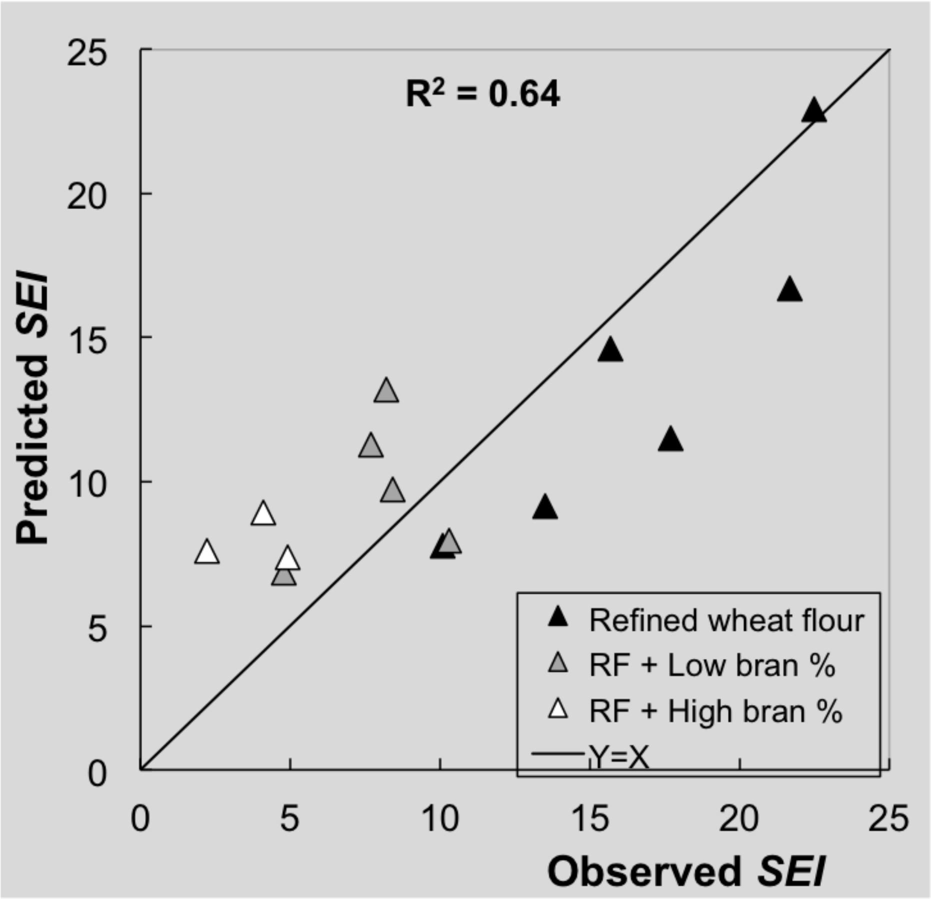
Computing the effect of water content on *SEI*



Model validation

Application of expansion model to experimental data from literatures (including Rheological behavior*) of wheat flour with bran (Robin et al., 2011)

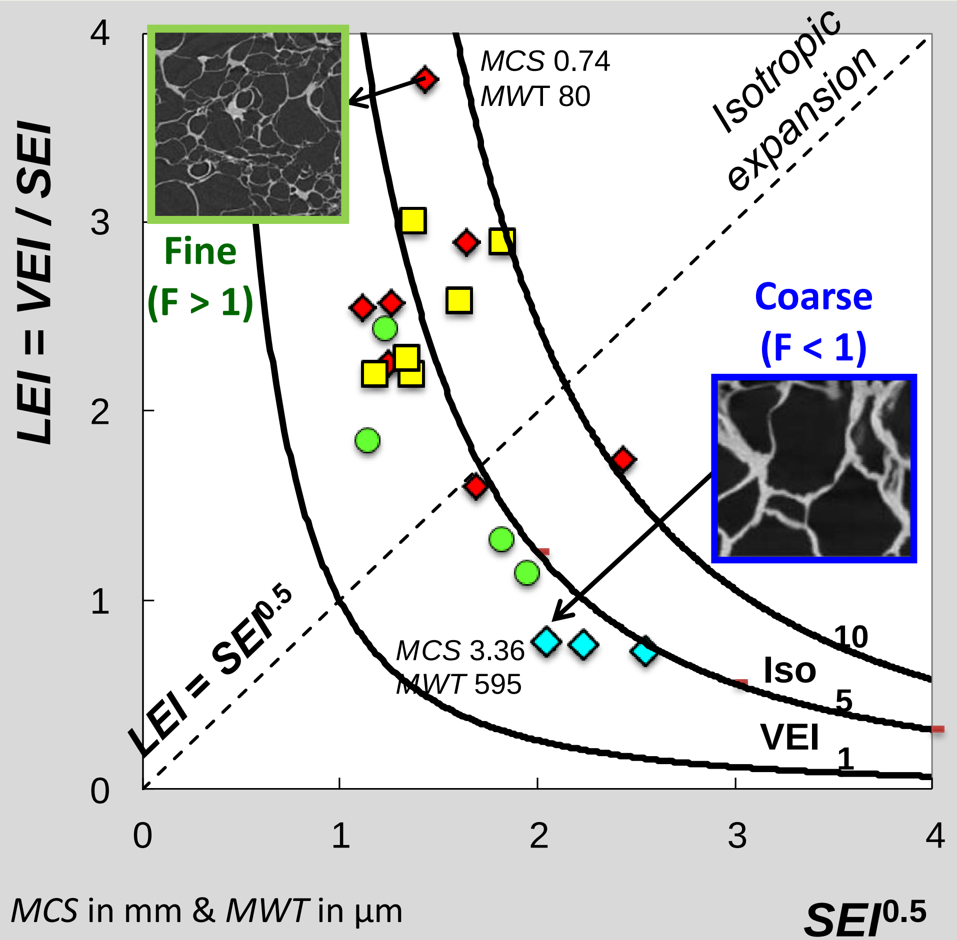




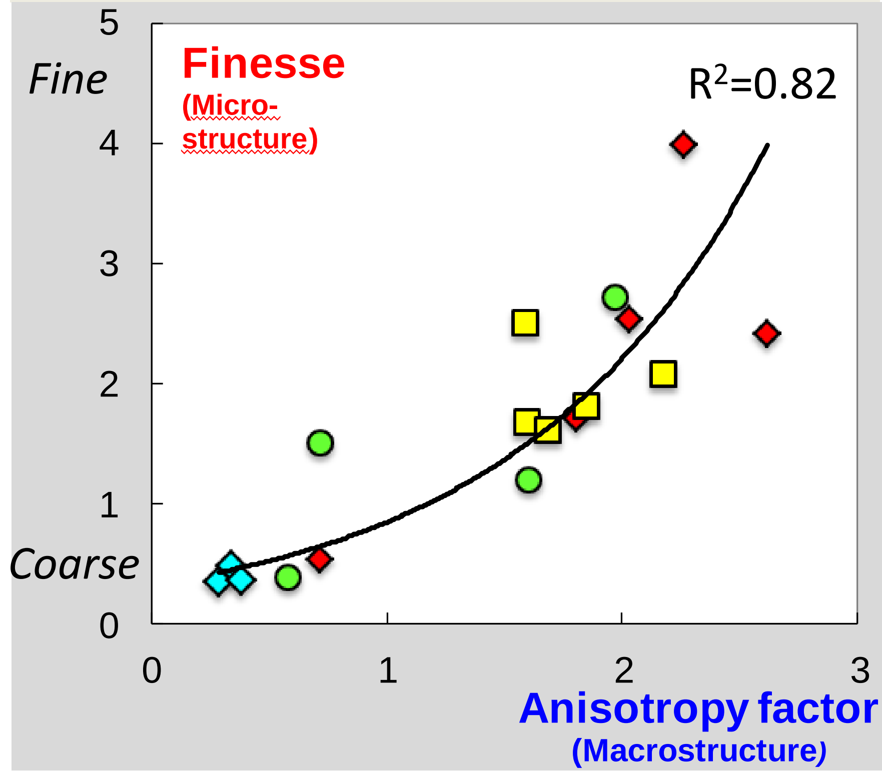
*Difficult to find in the literature

Anisotropy & **cellular structure**: from **macro** to **micro**-scale

Mapping of Anisotropy & Cellular structure
Experimental Data from Babin et al. (2007)



Variations of Anisotropy Factor (macrostructure) and Cellular Fineness (microstructure)



The higher *AF*,
the **finer the cellular structure.**

Axial expansion (*LEI*) is more favorable to **finer cells**

Conclusions

- A robust model for starch expansion by extrusion has been established, thanks to the integration of scientific knowledge and experimental data
- Cell fineness was modeled from computed anisotropy factor, providing a **link between micro and macroscopic scales**

Ongoing & Perspective

- Coupling mechanical model of extrusion (Ludovic®) with phenomenological model **of expansion**
  - ✓ The new Ludovic®'s outputs: Macro and cellular structures of foams
- Extending the domain of application of the model and the software

Dissemination

Articles

Modeling of starchy melts expansion by extrusion (A review).
Trends in Food Sci. & Tech (**submitted**).

A phenomenological model of starch expansion by extrusion.
Rhéologie (**accepted**); Food & Bioprocess Tech. (**in prep**.)

Congress

Annual European Rheology Conference **(AERC)**, April 2014, Karlsruhe. Poster.

Congrès du Groupe Français de Rhéologie **(GFR)**, October 2014, Grenoble. Oral.

Annual European Rheology Conference **(AERC)**, April 2015, Nantes. Oral.

International Congress on Engineering and Food **(ICEF)**, June 2015, Québec. Poster.

American Assc. Cereal Chemists Int. (**AACCI**), October 2015, Minnesota. Poster/Oral?

Symposium

Ludovic Club, March **2014**, Lyon. Analysis of the expansion phenomenon during the extrusion process: Experiments and model. Oral.

Ludovic Club, March **2015**, Grenoble. Modeling starch expansion by twin screw extrusion. Oral.

Thank you for your attention

Discussion....